

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering & Computer Science
6.041/6.431: Probabilistic Systems Analysis
(Quiz 1 | Spring 2009)

Question 1

Multiple Choice Questions: **CLEARLY** circle the appropriate choice. Scratch paper is available if needed, though **NO** partial credit will be given for the Multiple Choice.

a. Which of the following statements is NOT true?

(i) If $A \subset B$, then $\mathbf{P}(A) \leq \mathbf{P}(B)$.

(ii) If $\mathbf{P}(B) > 0$, then $\mathbf{P}(A|B) \geq \mathbf{P}(A)$.

(iii) $\mathbf{P}(A \cap B) \geq \mathbf{P}(A) + \mathbf{P}(B) - 1$.

(iv) $\mathbf{P}(A \cap B^c) = \mathbf{P}(A \cup B) - \mathbf{P}(B)$.

b. We throw n identical balls into m urns at random, where each urn is equally likely and each throw is independent of any other throw. What is the probability that the i -th urn is empty?

(i) $\left(1 - \frac{1}{m}\right)^n$

(ii) $\left(1 - \frac{1}{n}\right)^m$

(iii) $\binom{m}{n} \left(1 - \frac{1}{n}\right)^m$

(iv) $\binom{n}{m} \left(\frac{1}{m}\right)^n$

c. We toss two fair coins simultaneously and independently. If the outcomes of the two coins are the same, we win; otherwise, we lose. Let A be the event that the first coin comes up heads, B be the event that the second coin comes up heads, and C be the event that we win. Which of the following statements is false?

(i) Events A and B are independent.

(ii) Events A and C are *not* independent.

(iii) Events A and B are *not* conditionally independent given C .

(iv) The probability of winning is $1/2$.

d. For a biased coin, the probability of “heads” is $1/3$. Let h be the number of heads in five independent coin tosses. What is the probability $\mathbf{P}(\text{first toss is a head} \mid h = 1 \text{ or } h = 5)$?

(i) $\frac{\frac{1}{3}(\frac{2}{3})^4}{5\frac{1}{3}(\frac{2}{3})^4 + (\frac{1}{3})^5}$

(ii) $\frac{\frac{1}{3}(\frac{2}{3})^4}{\frac{1}{3}(\frac{2}{3})^4 + (\frac{1}{3})^5}$

(iii) $\frac{\frac{1}{3}(\frac{2}{3})^4 + (\frac{1}{3})^5}{5\frac{1}{3}(\frac{2}{3})^4 + (\frac{1}{3})^5}$

(iv) $\frac{1}{5}$

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e. A well-shuffled deck of 52 cards is dealt evenly to two players (26 cards each). What is the probability that player 1 gets all the aces?

(i) $\frac{\binom{48}{22}}{\binom{52}{26}}$

(ii) $\frac{4 \binom{48}{22}}{\binom{52}{26}}$

(iii) $\frac{48! 52!}{22! 26!}$

(iv) $\frac{4! \binom{48}{22}}{\binom{52}{26}}$

f. Suppose X, Y and Z are three independent discrete random variables. Then, X and $Y + Z$ are

- (i) always
- (ii) sometimes
- (iii) never

independent.

g. To obtain a driving licence, Mina needs to pass her driving test. Every time Mina takes a driving test, with probability $1/2$, she will clear the test independent of her past. Mina failed her first test. Given this, let Y be the additional number of tests Mina takes before obtaining a licence. Then,

- (i) $E[Y] = 1$.
- (ii) $E[Y] = 2$.
- (iii) $E[Y] = 0$.

h. Consider two random variables X and Y , each taking values in $\{1, 2, 3\}$. Let their joint PMF be such that for any $1 \leq x, y \leq 3$,

$$P_{X,Y}(x, y) = \begin{cases} 0 & \text{if } (x, y) \in \{(1, 3), (2, 1), (3, 2)\} \\ \text{strictly positive} & \text{otherwise.} \end{cases}$$

Then,

- (i) X and Y can be independent or dependent depending upon the *strictly positive* values.
- (ii) X and Y are always independent.
- (iii) X and Y can never be independent.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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- i. Suppose you play a *matching coins* game with your friend as follows. Both you and your friend have a coin. Each time, you two reveal a side (i.e. H or T) of your coin to each other simultaneously. If the sides match, you WIN a 1 from your friend and if sides do not match then you lose a 1 to your friend. Your friend has a complicated (unknown) strategy in selecting the sides over time. You decide to go with the following simple strategy. Every time, you will toss your unbiased coin independently of everything else, and you will reveal its outcome to your friend (of course, your friend does not know the outcome of your random toss until you reveal it). Then,
- (i) On average, you will lose money to your smart friend.
 - (ii) On average, you will neither lose nor win. That is, your average gain/loss is 0.
 - (iii) On average, you will make money from your friend.
- j. Let $X_i, 1 \leq i \leq 4$ be independent Bernoulli random variable each with mean $p = 0.1$. Let $X = \sum_{i=1}^4 X_i$. That is, X is a Binomial random variable with parameters $n = 4$ and $p = 0.1$. Then,
- (i) $E[X_1|X = 2] = 0.1$.
 - (ii) $E[X_1|X = 2] = 0.5$.
 - (iii) $E[X_1|X = 2] = 0.25$.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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Question 2:

Alice and Bob both need to buy a bicycle. The bike store has a stock of four green, three yellow, and two red bikes. Alice randomly picks one of the bikes and buys it. Immediately after, Bob does the same. The sale price of the green, yellow, and red bikes are \$300, \$200 and \$100, respectively.

Let A be the event that Alice bought a green bike, and B be the event that Bob bought a green bike.

a. What is $\mathbf{P}(A)$? What is $\mathbf{P}(A|B)$?

b. Are A and B independent events? Justify your answer.

c. What is the probability that at least one of them bought a green bike?

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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6.041/6.431: Probabilistic Systems Analysis
(Quiz 1 | Spring 2009)

- d. What is the probability that Alice and Bob bought bicycles of different colors?
- e. Given that Bob bought a green bike, what is the expected value of the amount of money spent by Alice?
- f. Let G be the number of green bikes that remain on the store after Alice and Bob's visit. Compute $\mathbf{P}(B|G = 3)$.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering & Computer Science
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(Quiz 1 | Spring 2009)

Question 3:

Magic Games Inc. is a store that sells all sorts of fun games. One of its popular products is its magic 4-sided dice. The dice come in pairs; each die can be fair or crooked, and the dice in any pair can function independently or, in some cases, can have magnets inside them that cause them to behave in unpredictable ways when rolled together.

Xavier and Yvonne together buy a pair of dice from this store. Each of them picks a die in the pair; one of them then rolls the two dice together. Let X be the outcome of Xavier's die and Y the outcome of Yvonne's die. The joint PMF of X and Y , $p_{X,Y}(x,y)$, is given by the following figure:

	4	$\frac{1}{20}$	$\frac{1}{20}$	$\frac{1}{20}$	$\frac{1}{10}$
	3	$\frac{1}{20}$	$\frac{1}{20}$	$\frac{1}{10}$	$\frac{1}{20}$
Y	2	$\frac{1}{20}$	$\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$
1		$\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{20}$	$\frac{1}{20}$
		1	2	3	4
			X		

(a) Find the PMF of the outcome of Xavier's die, $p_X(x)$.

(b) Find the PMF of the outcome of Yvonne's die, $p_Y(y)$.

(c) Are X and Y independent?

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering & Computer Science
6.041/6.431: Probabilistic Systems Analysis
(Quiz 1 | Spring 2009)

Zach and Wendy are intrigued by Xavier and Yvonne's dice; they visit the store and buy a pair of dice of their own. Again, each of them picks a die in the pair; one of them then rolls the two dice together. Let Z be the outcome of Zach's die and W the outcome of Wendy's die. The joint PMF of Z and W , $p_{Z,W}(z,w)$, is given by the following figure:

	4	$\frac{1}{12}$	$\frac{1}{24}$	$\frac{1}{12}$	$\frac{1}{24}$
	3	$\frac{1}{12}$	$\frac{1}{24}$	$\frac{1}{12}$	$\frac{1}{24}$
W	2	$\frac{1}{12}$	$\frac{1}{24}$	$\frac{1}{12}$	$\frac{1}{24}$
	1	$\frac{1}{12}$	$\frac{1}{24}$	$\frac{1}{12}$	$\frac{1}{24}$
		1	2	3	4
		Z			

The store also sells a variety of magic coins, some fair and some crooked. Alice buys a coin that on each toss comes up heads with probability $3/4$.

- (d) Wondering whether to buy some dice as well, Alice decides to try out her friends' dice first. She does the following. First, she tosses her coin. If the coin comes up heads, she borrows Xavier and Yvonne's dice pair and rolls the two dice; if the coin comes up tails, she borrows Zach and Wendy's dice pair and rolls those instead. What is the probability that she rolls a double, i.e., that both dice in the pair she rolls show the same number?

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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(Quiz 1 | Spring 2009)

- (e) Alice has still not made up her mind about the dice. She tries another experiment. First, she tosses her coin. If the coin comes up heads, she takes Xavier and Yvonne's dice pair and rolls the dice repeatedly until she gets a double; if the coin comes up tails, she does the same with Zach and Wendy's dice. What is the expected number of times she will need to roll the dice pair she chooses? (Assume that if a given pair of dice is rolled repeatedly, the outcomes of the different rolls are independent.)
- (f) Alice is bored with the dice and decides to experiment with her coin instead. She tosses the coin until she has seen a total of 11 heads. Let R be the number of tails she sees. Find $\mathbf{E}[R]$. (Assume independent tosses.)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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- (g) Alice is still playing with her coin. Let A be the event that the second head she sees occurs on the 7th coin toss, and let S be the position of the first head. Find the conditional PMF of S given the event A , $p_{S|A}(s)$.
- (h) Alice's friend Bob buys a coin from the same store that turns out to be fair, i.e., that on any toss comes up heads with probability $1/2$. He tosses the coin repeatedly until he has seen either a total of 11 heads or a total of 11 tails. Let U be the number of times he will need to toss the coin. Find the PMF of U , $p_U(u)$. (Assume independent tosses.)

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